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Calculation of Wave Run-up Height in South Baltic Sea: Case Study at Coastal Research Station at Lubiatowo, Poland *

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Abstract

The paper presents recent investigations of beach run-up phenomena at the Coastal Research Station of the Institute of Hydro-Engineering of the Polish Academy of Sciences at Lubiatowo, Poland. The local beach is typical of open-sea coasts of the south Baltic Sea, featuring multiple longshore bars that form predominantly dissipative systems. Measurements were taken to verify the existing formulas for the run-up height, bearing in mind that they had been derived for entirely different, oceanic conditions. The results indicate that these formulations can be adapted to south Baltic Sea conditions. This however, will require significantly larger data sets, which we intend to obtain in the near future.

Key words: Wave run-up; statistics; dissipative beach; Baltic Sea

1. Introduction

The position of the shoreline at a given seawater level, including wave run-up, is probably the most important quantity investigated in coastal dynamics. Shoreline oscillations are produced by interaction between waves and the beach, with a consequent absorption and/or reflection of wave energy. When waves approach the coast, most of their energy is dissipated across the surf zone by wave breaking. However, some of that energy is convertedinto potential energy in the form of run-up on the beach foreshore (Hunt 1959). Run-up phenomena play a critical role in dune erosion during storms, so research is focused primarily on the estimation of extreme run-up during such events, needed for accurate predictions of the impact of storms and potential damage on the coast. The waves running up beaches and hitting dunes during storms (high seawater level, stormy waves) lower beach elevations and cut dune foots, causing their destruction and contributing to coastline erosion. For this reason,wave run-up has been attracting wide engineering attention and remains one of key research topics in coastal

* This paper is dedicated to the memory of Professor Zbigniew Pruszak (1947–2018).

science. Generally, the wave run-up includes two dynamically different processes: 1) time-averaged wave set-up, in which the water level is elevated to balance the on-shore momentum flux (radiation stress) resulting from wave breaking, and 2) a time-varying component called "swash", which represents alternating up-and-down water motion at the beach face. In general, formulas describing the beach run-up height (R) originate from the formula proposed by Hunt (1959), in which the height of beach run-up is a function of the deep-water wave height and period and the mean beach slope. Gradual improvements in measurement techniques and numerical methods have led to various modifications of that basic concept.

Several wave run-up measurement techniques have been used on natural beaches over the years. Experiments performed by Guza and Thornton (1982), using a dual--resistance wire, revealed that the significant vertical run-up excursion on a gently sloping dissipative natural beach was equal to 70% of the significant offshore wave height.

Holman and Guza (1984) conducted a series of field experiments at a dissipative beach characterized by a low slope ($\beta \sim 0.02$) and moderate wave heights ($H \sim 1.0$ m). Their main objective was to evaluate and compare two wave run-up measurement techniques on natural beaches: one using resistance wires and the other involving video recordings. Since the 1980s, video techniques have gradually taken hold. This is basically due to the possibility of making measurements even during extreme events (storms).

Ruggiero et al (2001, 2004) and Stockdon et al (2006) carried out run-up measurements using video recording techniques. They came up with the so-called "time-stack" method (e.g. Aagard and Holm 1989, Holland and Holman 1993, 1999), which allows vertical wave run-up elevation time series to be extracted from raw video recordings. The purpose of these modifications is to include parameters/quantities making it possible to more precisely estimate the range of beach run-up for the local hydrodynamic and morphological conditions of a given coastal segment. The most important ones are presented further below to serve as a footing for the current analysis. The major goal of this paper is a preliminary comparison and verification of state-of-the-art beach run-up formulas in the context of the latest measurements done at the Coastal Research Station (CRS) of IBW PAN at Lubiatowo. These measurements were taken using a novel video technique that made it possible to perform a detailed and in-depth analysis of run-up phenomena at a predominantly dissipative beach.

2. State of the Art

The processes of beach wave run-up and run-down depend on wave breaking patterns, which can be determined by the so-called surf similarity parameter, known as the Battjes number, Battjes (1974b) or the Iribarren number. Initially, this parameter was defined for regular waves:

$$\xi_o = \frac{\tan\beta}{s_o}, \tag{1}$$

where:

- β – beach slope;
- s_o – deep-water wave steepness $\left(s_o = \sqrt{H_o/L_o}\right)$;
- H_o – averagedeep-water wave height;
- L_o – deep-water wavelength $\left(L_o = gT^2/2\pi \approx 1.56\,T^2\right)$;
- g – acceleration of gravity;
- T – wave period.

In some formulations, the breaking wave height H_b is used instead of H_o, in which case the surf similarity parameter is denoted as ξ_b.

In the original Hunt formulation, the beach wave run-up height was related to the average deep-water wave height and period:

$$\frac{R}{H_o} = \xi_o, \tag{2}$$

where R – beach wave run-up height.

Battjes (1974a) adapted the original Hunt's formula to irregular (wind-driven) waves:

$$\frac{R_{2\%}}{H_s} = C_m\,\xi_{om}, \tag{3}$$

where:

- $R_{2\%}$ – the beach wave run-up of irregular wind waves assuming that 2% of all wave trains will exceed the calculated run-up height;
- C_m – numerical coefficient in the range of 1.49–1.87;
- H_s – significant wave height defined as the average of the highest 1/3 of wave heights.

$$\xi_{om} = \frac{\tan\beta}{\sqrt{\dfrac{H_s}{L_{om}}}}, \tag{4}$$

$$L_{om} = \frac{g{T_m}^2}{2\pi}, \tag{5}$$

where:

- L_{om} – linear theory mean wave length in deepwater;
- T_m – mean wave period.

Ahrens (1981), upon a series of wave flume experiments, found that the Battjes formula should be modified for beaches with slopes between 1 : 1 and 1 : 4. He proposed a new value of the coefficient $C_m = 1.6$ and, instead of the mean wave period, recommended the use of the peak period T_p. Holman (1986), using measurements taken at the Duck field station in North Carolina (the U. S.), found that the beach run-up height for natural beaches is far better described by the formula

$$\frac{R_{2\%}}{H_{mo}} = a\xi_{op}^{b} + c, \tag{6}$$

where:

$a = 0.83$;
$b = 1$;
$c = 0.2$;
$H_{mo} = 4\sqrt{m_o}$ – energy-based significant wave height;
m_o – zero$^{\text{th}}$ moment of the wave energy density spectrum;
$\xi_{op} = \tan\beta_f \,/\, \sqrt{H_{mo}/L_{op}}$;
β_f – foreshore beach slope;
$L_{op} = gT_p{}^2/2\pi$;
T_p – peak wave period.

Mase (1989), investigating the results of laboratory tests (for $\xi_{op} > 2$), proposed another improvement to Hunt's formula:

$$\frac{R_{2\%}}{H_{mo}} = 1.86\,\xi_{op}^{0.71}. \tag{7}$$

Ruggiero et al (2001), using extensive measurements on the coast of Oregon (the U.S.), provided a simple equation:

$$R_{2\%} = 0.27\left(\tan\beta\; H_{mo}L_{op}\right)^{1/2}. \tag{8}$$

Stockdon et al (2006) further developed Holman's approach on the basis of experimental investigations. They classified beach profiles as dissipative systems (for $\xi_{op} < 0.3$) or reflective systems (for $\xi_{op} > 1.25$) and came up with a formula describing the run-up height in a more complicated form:

$$R_{2\%} = 1.1\left[0.35\beta_f\left(H_{mo}\,L_{op}\right)^{1/2} + \frac{1}{2}\left(H_{mo}L_{op}\left(0.563\beta_f{}^2 + 0.004\right)\right)^{1/2}\right], \tag{9}$$

$$R_{2\%} = 0.043\left(H_{mo}L_{op}\right)^{1/2} \quad \text{for} \quad \xi_{op} < 0.3. \tag{10}$$

The formulations presented above indicate that all formulas describing the beach run-up height (R) are variations of Hunt's approach, in which beach run-up phenomena depend on the height and period of deep-water waves and the average foreshore beach slope. Modifications of this basic concept seek to include other parameters controlling run-up phenomena and linking them to local hydrodynamic and morphological characteristics of a given coastal segment in order to obtain more exact estimates of beach run-up height.

Carrier and Greenspan (1958), by analytically solving nonlinear shallow-water equations for inviscid fluids, showed that a monochromatic non breaking wave solution exists when

$$\varepsilon_s = \frac{a_s \omega^2}{g \tan^2 \beta} \leq 1, \tag{11}$$

where:

- a_s – vertical swash oscillation;
- ω – incident wave radian frequency;
- g – acceleration of gravity;
- β – plane beach slope.

Eq. (11) is the basis for determination of the beach run-up height on natural shores in the presence of infragravity waves. It demonstrates that, for saturated (maximum) beach run-up conditions, the height of a run-up wave is the function of the beach slope and the period of the standing wave. Importantly, it does not depend on the height of incoming waves. The problems with practical applications of Eq. (11) are related, on the one hand, to precise determination of the dimensionless coefficient ε_s and, on the other hand, to determination of standing-wave parameters. The value of ε_s has been assessed by various researchers, who produced fairly divergent results. Battjes (1974a) determined an approximate value of this parameter to be 1.25. Guza and Bowen (1975), through laboratory experiments, obtained the value of $\varepsilon_s \approx 3 \pm 1$, whereas van Dorn (1976), also using lab experiments,found the value of $\varepsilon_s \approx 2 \pm 0.3$. A study by Huntley et al (1977), based on the results of field measurements, suggests that ε_s is in the range of 2–3. Baldock and Holmes (1999) recommend the value of $\varepsilon_s \approx 2.5$ for both regular and random waves on the basis of measurements of run-up heights in laboratory experiments. Stockdon et al (2006) analyzed swash and run-up data collected in 10 fields experiments representing a wide variety of wave conditions for dissipative, intermediate and reflective beaches in order to propose a universal formulation capable of representing wave run-up heights for a wide spectrum of natural beaches. The proposed formulation is as follows:

$$R_{2\%} = 1.1 \left[\langle \eta \rangle + \frac{S}{2} \right], \tag{12}$$

where $R_{2\%}$ represents 2% run-up exceedance calculated from the cumulative probability density function of run-up elevation; $\langle \eta \rangle$ is the time-averaged water level at the shoreline, and S denotes time-varying vertical fluctuations about the temporal mean. The coefficient 1.1 takes into account a small asymmetry of the probability distribution function (skewness) due to the non-Gaussian nature of swash.

Swash, in turn, is given by the sum of incident and infragravity components:

$$S = \sqrt{(S_{inc})^2 + (S_{ig})^2}, \tag{13}$$

S_{inc} is the incident swash component (i.e. $f > 0.05$ Hz), and S_{ig} is the infragravity one (i.e $f \leq 0.05$ Hz). The video technique applied consists in creating cross-shore transects of pixel intensity (or timestakes), that is, a two-dimensional representation of wave run-up in time and the cross-shore x coordinate, from which it is possible to obtain time series of water level elevation measured relative to the mean sea level through digitalization of the wave run-up forehead (i.e. the leading edge) developing at cross-shore transects. For these time series, with durations of up to 17 minutes, tidal effects were subtracted to obtain the wave set-up. After removing the set-up component, it is possible to derive the swash statistic from the spectrum $PSD(f)$, obtained from the water level time series.

The significant swash height S was calculated as

$$S = 4\sqrt{PSD\,(f)\,df}. \tag{14}$$

The following expressions for wave set-up and swash were proposed:

$$\langle\eta\rangle = 0.35\beta_f\left(H_{mo}L_{op}\right)^{1/2}, \tag{15}$$

$$S_{inc} = 0.75\beta_f\left(H_{mo}L_{op}\right)^{1/2}, \tag{16}$$

$$S_{ig} = 0.06\left(H_{mo}L_{op}\right)^{1/2}. \tag{17}$$

Based on the entire data set, the universal run-up formulation valid for all types of beaches is

$$R_{2\%} = 1.1\left(0.35\,\beta_f\left(H_{mo}L_{op}\right)^{1/2} + \frac{\left[H_{mo}L_{op}\left(0.563\beta_f^2 + 0.004\right)\right]^{1/2}}{2}\right). \tag{18}$$

It should be noted that the wave set-up and incident swash are both functions of the Iribarren parameter ξ_{op}, whereas the infragravity swash is also a function of the wave height and offshore wavelength, but is statistically independent of both the foreshore and the surf zone slopes. However, it was pointed out that, for dissipative beaches (i.e. $\xi_{op} < 0.3$) both the wave set-up and swash are statistically independent of the foreshore beach slope β_f:

$$\langle\eta\rangle_d = 0.016\left(H_{mo}L_{op}\right)^{1/2}, \tag{19}$$

$$S_d = 0.046\left(H_{mo}L_{op}\right)^{1/2}. \tag{20}$$

For extremely dissipative beaches, swash is entirely dominated by the infragravity component, since energy in the incident band is saturated: an additional increase in H_{mo} contributes only to increasing the infragravity component, while the incident one remains constant as saturated. Therefore, for dissipative beaches, the wave run-up height formulation reduces to Eq. (10). In the case of intermediate and reflective beaches, an increase in H_{mo} and T_p increases both the incident and infragravity swash components. In the case of highly reflective beaches (i.e. $\xi_{op} > 1.25$), where swash is entirely dominated by the incident energy component and the contribution of the infragravity component can be completely neglected, the run-up expression is as follows:

$$R_{2\%} = 0.73\beta_f \left(H_{mo}L_{op}\right)^{1/2}. \tag{21}$$

3. Study Site

The run-up phenomena were investigated at the Coastal Research Station of IBW PAN at Lubiatowo on the South Baltic coast (Fig. 1). The beach there has a very low curvature and is almost perfectly straight. The shore-normal azimuth equals ca. 343°, so the beach has basically an East-West orientation. It is characterized by a gently inclined seabed ($\beta \approx 0.015$) and is composed of fine-grained quartz sand with an average grain diameter of $d_{50} \approx 0.22$ mm. The thickness of sand sediments in the backshore zone is 3–5 m. In the seashore profiles, 3–4 nearshore bars occur. The first of them, R_I, is located at a distance of about $100 \div 120$ m from the shoreline, second (R_{II}) at about 200 m, third (R_{III}) at about $300 \div 350$ m, whereas the fourth (R_{IV}) and possible fifth at about $550 \div 850$ m (Fig. 2). In addition, the so-called ephemeral bar R_0 occurs in the form of a flat underwater shallow. It migrates towards or away from the coastline, depending on transient hydrologic and hydrodynamic conditions, Ostrowski et al (2016).

Wave climate measurements have been performed since 1997 by IBW PAN using a directional wave buoy, located at depths of 16–20 m. Table 1 shows that waves from the western sector (SW, W and NW) occur over 50% of the year, those from the eastern sector (NE, E, SE) over ca. 32%, and those from the shore-normal sector over ca. 13.5%. The most frequent wave heights are from the 0.5–1.5 m class, and they are seen over ca. 47% of the year. Table 1 also presents percentages of occurrence [%] for significant wave heights for given heights and azimuths of wave direction.

Tides are insignificant in the Baltic Sea, so the Polish maritime area is defined as a non-tidal region. Representative water levels corresponding to a given probability of occurrence for the CRS Lubiatowo are adopted from a nearby mareographic station at the Ustka port. The long-term mean water level is about 500 cm with respect to Amsterdam Ordnance Datum or Normaal Amsterdams Peil (NAP). The absolute maximum and minimum of seawater levels at CRS Lubiatowo (Ustka Port) from the mid-19th century until 2007 are as follows:

absolute maximum – 668 cm, recorded on Dec. 15, 1898,
absolute minimum – 396 cm, recorded on Feb. 10, 1897.

Fig. 1. Location of the study site

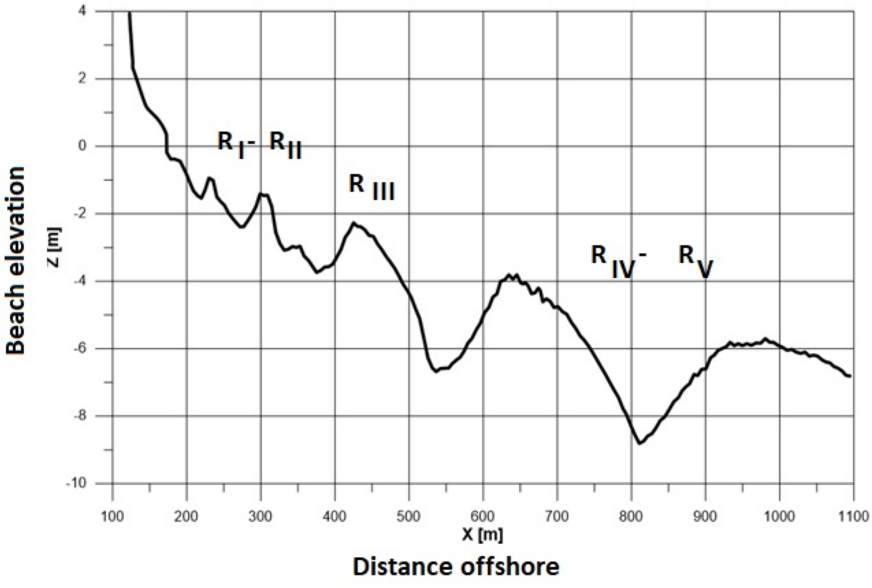

Fig. 2. Typical profile in the study area

4. Field Measurements

The current research was aimed at the verification of run-up formulas upon the basis of field measurements done at the Coastal Research Station of IBW PAN at Lubiatowo. The study included local, Baltic Sea conditions and parameters, such as storm surge heights, geo-technical parameters of local sediment, and the morphological con-

Table 1. Significant wave height occurrence [%] for different wave height classes and wave directions

Significant wave height classes [m]	N	NE	E	SE	S	SW	W	NW	Total
0.0÷0.5	3.06	6.84	5.72	0.32	1.31	0.38	8.35	3.19	29.18
0.5÷1.5	5.90	12.60	2.75	0.11	0.18	0.04	21.74	4.00	47.32
1.5÷2.5	3.06	3.22	0.02	0.00	0.00	0.00	10.94	2.23	19.47
2.5÷3.5	0.99	0.20	0.00	0.00	0.00	0.00	1.73	0.50	3.42
>3.5	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.61
Total	13.5	22.9	8.50	0.43	1.49	0.41	42.76	10.03	100.0

figuration of the emerged and submerged beach. These parameters are necessary for precise assessments of beach and dune erosion. In the event of negative verification of the existing formulas, it was planned to establish an empirical formula describing beach run-up phenomena for the Polish coast, situated in the south Baltic Sea region.

During storms, wave run-up phenomena exhibit a notable diversification of spatial patterns (e.g. Guza and Inman 1975, Holman and Bowen 1984, Holland et al 1995, Holland and Holman 1996, Komar 1998). Under such conditions,"tongues" of deeper wave intrusions onto the beach can be observed in the alongshore direction, see Fig. 3. Field investigations at Lubiatowo showed that significant low-frequency harmonic components with periods ranging from 40 to 50 s and from 100 to 120 s exist in the shallow water area at depths of ca. 0.5 m. They can be interpreted as infragravity waves, Szmytkiewicz and Różyński (2016).

The latest measurements of wave run-up processes at CRS Lubiatowo were performed in Feb.–Mar. 2016. Their primary goal was to obtain a qualitative and quantitative estimate of the run-up by applying a relatively simple and low-cost methodology based on in situ video recordings of the run-up process and on their subsequent post-processing. Run-up processes should best be measured under relatively energetic hydrodynamic forcing – that is, the waves should be high enough to generate notable individual run-ups. However, not all measurements were carried out under such "rough" seas: some were taken under conditions of storm recess, when both wave and sea levels were decreasing.

Video recording required a stretch of beach where the run-up processescould be visually observed. The best site was foundnear the two wave gauges needed to collect data on surface elevation in shallow water and on the water level itself. In order to make the measurements compatible, a local reference base was established. It consisted of two extremely located posts with the known distance between them. The first post was placed at the offshore boundary of run-up phenomena at a seabed depth of about 0.5 m. The second one marked the maximum landward limit beyond which no wave run-up could be expected. In other words, the reference posts designated the cross-shore range of wave run-up oscillation. Their elevations were also used for the

Fig. 3. Rhythmic wave run-up structures at the Coastal Research Station at Lubiatowo

assessment of the local beach slope in the run-up region. These two main posts were supplemented by secondary posts, spaced every 0.5 m, so that the run-up extent could be captured with satisfactory precision. A video camera Forever SC-200 (resolution 1080FHD 1920 × 1080 and frequency 50/60 Hz) was then placed at a certain distance from the profile in such a way that both extreme posts could be captured in one frame continuously. The time window of the recordings was generally in the order of 45–60 minutes divided successively into twenty-minute recordings, so that the process could be considered stationary. The recordingswere usuallytaken both in the morning and in the afternoon. The recording setup of the camera and the two posts with marks between them are schematically shown in Fig. 4. In the second stage, the recordings were post-processed and drawn on a PC screen. Then, the points marked at each frame along the entire profile of the run-up wave were joined with straight lines so that the evolution of the run-up wave profile could be studied frame by frame. Moreover, vertical dashed segments were drawn to represent a fictitious, artificial reference base to be used later in the post-processing of video footage to determine the length of the wave run-up with greater precision. Ultimately, once the reconstructed profile had been drawn on a PC screen, the entire recording was projected, and a manual count of the length of each wave run-up was performed: the run-up extension L_R was defined as the distance from the first reference post to the i-th reference point reached by a given wave. Each length was subsequently converted into the wave run-up height

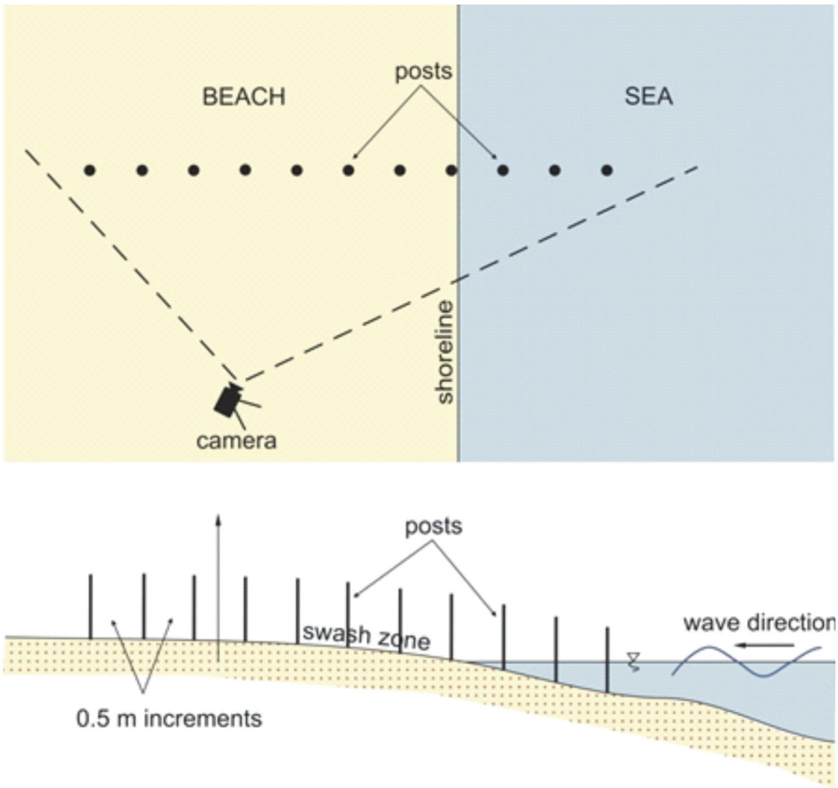

Fig. 4. Setup for beach run-up height recordings at Lubiatowo in 2016

using GPS-aided geo-referenced coordinates of the two reference posts according to the formula

$$R = L_R \frac{h_{up} - h_{down}}{l_{up} - l_{down}} - d = L_R \beta_f - d. \tag{22}$$

In Eq. (22), h_{up} denotes the elevation of the landward-most post, h_{down} represents the elevation of the offshore-most post, l_{up} and l_{down} are the corresponding horizontal co-ordinates, and d is the seabed depth at the offshore-most post (set to 0.3 ± 0.05 m for conditions in Fig. 5). Thus, a linearly sloping sea bottom was assumed in the swash zone. Furthermore, an auxiliary profile, parallel to the studied one, was geo-referenced in order to compare the measured and reconstructed profiles, see Fig. 5. In general, this profile line extended from the dune foot to the wave gauge. Hydrodynamic parameters of wave climate (the wave height, peak period and wave direction) were extracted from a buoy located off-shore in deep water. The wave run-up heights were then compared with the established formulations, valid for sandy mildly sloping beaches: Mase (1989), Holman (1986), Ruggiero et al (2001) and Stockdon et al (2006).

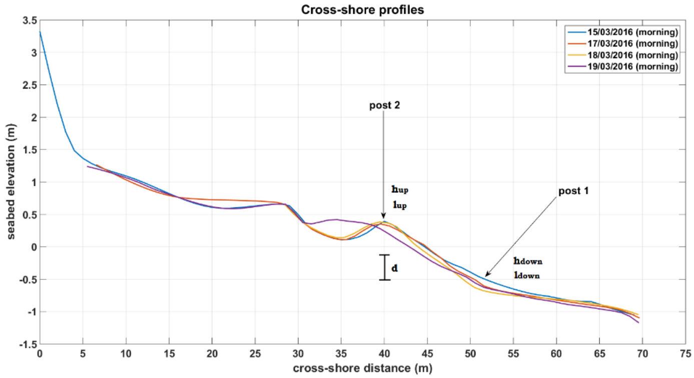

Fig. 5. Sea bottom in the swash area, Mar. 15–19, 2016

A detailed scrutiny of wave run-up phenomena was done for morning and afternoon recordings taken on March 15, 17, 18 and 19, 2016. Fig. 6 (a–d) and fig. 7 (a–d) present histograms and empirical probability density functions of the recorded wave run-ups, computed by Eq. (22) from individual up-beach wave excursions.

In order to compare these records with the results of beach run-up calculations by the existing formulas, offshore wave parameters at the time of run-up measurements were collected as well. They are put together in Table 2. Table 3 compares the recorded wave run-up heights $R_{2\%}$, read from empirical probability density functions, with their estimates obtained from Holman (1986), Mase (1989), Ruggiero et al (2001) and Stockdon et al (2006) – formulas (6), (7), (8) and (9) respectively.

Table 2. Offshore wave parameters during wave run-up measurements

Date	Recording time [min.]	Water level about Amsterdam mean [m]	Offshore significant wave height [m]	Peak wave period [s]	Azimuth of offshore wave approach [deg]
Mar. 15, 2016 morning	39	–0.14	1.30	6.25	23.9
Mar. 15, 2016 afternoon	22	–0.17	1.14	6.25	19.7
Mar. 17, 2016 morning	43	–0.15	0.89	4.76	292.5
Mar. 17, 2016 afternoon	41	–0.17	1.18	5.26	286.9
Mar. 18, 2016 morning	40	–0.03	0.81	5.26	292.5
Mar. 18, 2016 afternoon	43	–0.01	1.06	5.26	344.5
Mar. 19, 2016 morning	44	–0.13	1.54	5.26	312.2
Mar. 19, 2016 afternoon	41	–0.17	1.43	5.26	310.8

The comparison of results shows that in situations of mild and moderate wave climates that were encountered during the run-up measurements, the Mase formula provides highly overestimated run-up values. Holman's estimates were also mostly too

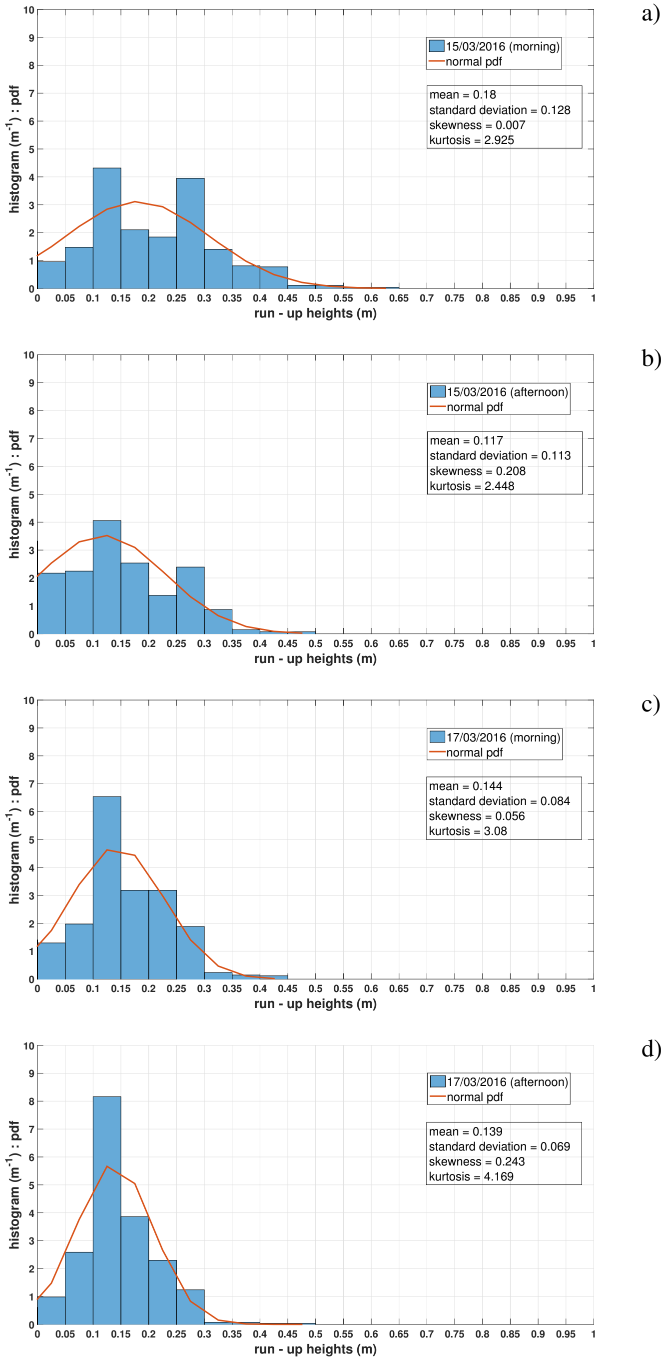

Fig. 6. Histograms and empirical probability density functions of wave run-up for a) Mar. 15, 2016, morning; b) Mar. 15, 2016, afternoon; c) Mar. 17, 2016, morning; d) Mar. 17, 2016, afternoon

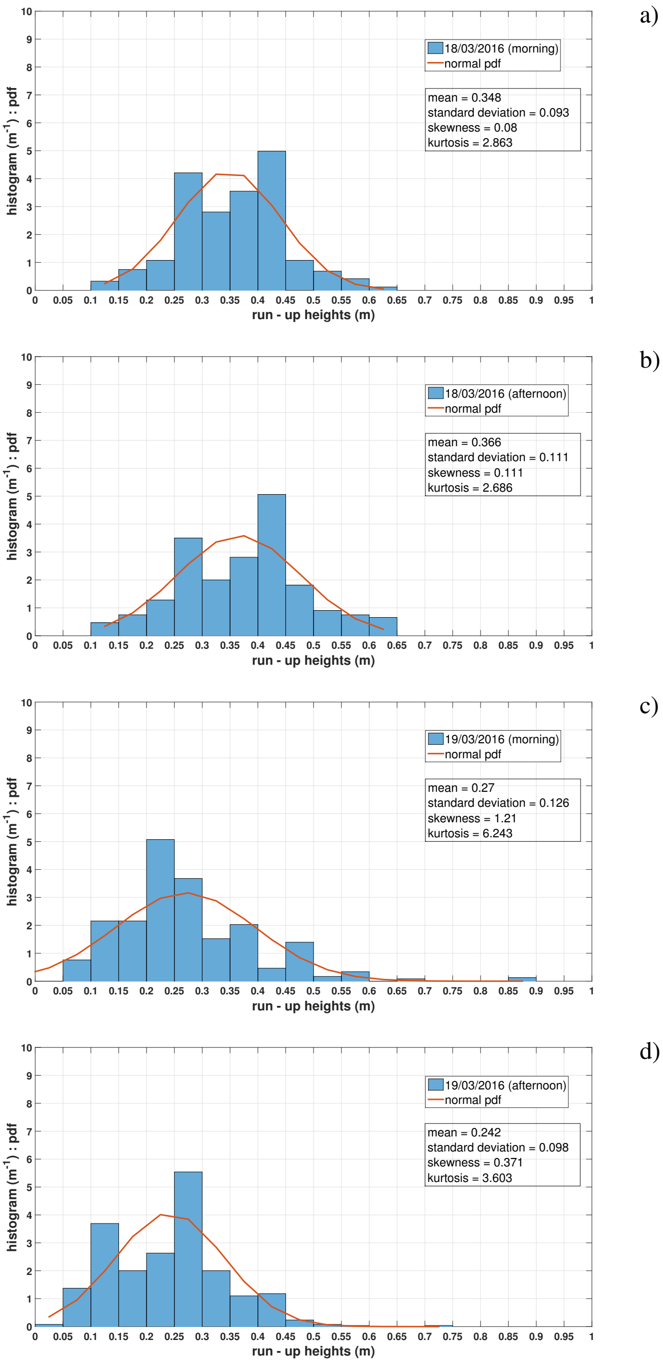

Fig. 7. Histograms and empirical probability density functions of wave run-up for a) Mar. 18, 2016, morning; b) Mar. 18, 2016, afternoon; c) Mar. 19, 2016, d) Mar. 19, 2016, afternoon

Table 3. Comparison of recorded and calculated wave run-up heights

Date	Recorded run-up heights $R_{2\%}$ [m]	Computed run-up heights			
		Holman (1986) [m]	Mase (1989) [m]	Ruggiero et al (2001) [m]	Stockdon et al (2006) [m]
Mar. 15, 2016 morning	**0.47**	0.78	1.43	0.65	0.66
Mar. 15, 2016 afternoon	**0.37**	0.71	1.31	0.61	0.62
Mar.17, 2016 morning	**0.32**	0.50	0.92	0.41	0.42
Mar. 17, 2016 afternoon	**0.30**	0.65	1.19	0.52	0.53
Mar. 18, 2016 morning	**0.55**	0.51	0.94	0.43	0.44
Mar. 18, 2016 afternoon	**0.63**	0.61	1.11	0.49	0.50
Mar. 19, 2016 morning	**0.53**	0.78	1.42	0.55	0.55
Mar. 19, 2016 afternoon	**0.50**	0.74	1.35	0.56	0.57

high, but the discrepancies were significantly less conspicuous. Finally, Ruggiero's and Stockdon's assessments of wave run-up heights were very similar and provided the most accurate estimates of run-up heights.

5. Conclusions

The results indicate that some of the existing formulas of beach wave run-up can be applied to the highly dissipative shores of the south Baltic Sea after some minor modifications. In particular, this conclusion applies to Ruggiero's and Stockdon's formulas, because they have only one numerical coefficient, originally set to 0.27 and 0.043, respectively. They can be easily adjusted by a least-square fit to a sufficiently ample run-up data set. For this purpose, more measurements are plannedby means of two advanced digital cameras recording run-up processes simultaneously in the longshore and cross-shore directions. Then, an automated procedure for identification of individual wave up-beach excursions will be applied, the corresponding run-ups calculated, and their statistics determined. Finally, a least-square fit to a much larger data set should establish a coefficient valid for the conditions of the Polish coast in the Ruggiero/Stockdon formulas. A modification of Holman's formula is not equally straightforward conceptually, since it contains 3 parameters, and their different sets can produce similar least-square minima. It seems reasonable though to keep the exponent b and the free parameter c fixed at their current values and to manipulate the factor a only. Only if the results are still insufficiently precise (e.g. when compared to the adjusted Ruggiero/Stockdon formulas) can a more sophisticated, simultaneous manipulation of two or three parameters be recommended. These modifications are planned to be investigated in the follow-up research in the same way as those of the Ruggiero/Stockdon formulas, with the exception of more complicated tuning of least-square fitted parameters. The results demonstrate that run-up processes exhibit notable differences with respect to other case studies on which the currently existing run-up formulas are based. Thus, the present study introduces some conceptual novelty. Another novel element is the video recording of run-up processes.In the follow-up research, this technique will be automated, providing another contribution to the development of in-situ data acquisition techniques in coastal science.

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